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Impact of unusual monsoonal rainfall in structuring meiobenthic assemblages at Sundarban estuarine system, India

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ABSTRACT

The present study investigates the impact of monsoon on meiofaunal and free-living nematode communities of the Sundarban estuarine system (SES) both from taxonomic and functional point of view. In 2013, SES experienced an unusual rainfall event followed by cloud burst event at upper Himalayan regime. Average meiobenthic abundance declined considerably in the study area from early phase of monsoon (EM) (699 ± 1569.4 ind. 10 cm^{-2}) to later one (LM) (437 ± 949.9 ind. 10 cm^{-2}) probably due to high annual rainfall which completely flushed the estuary. Free-living marine nematodes were the dominant group among all other meiobenthic taxa in both phases of monsoon. Nematode community was made up of 49 genera in 22 families. Comesomatidae, Chromadoridae, Linhomoeidae and Xylidae were the richest and most abundant families. During both phases of monsoon, stations, which were represented by fine sediments and high amount of organic carbon, harbored higher meiofaunal densities and nematode diversity with a strong dominance of 1B and 2B trophic guilds of nematodes. Different feeding guilds of nematode would be able to reveal anthropogenic-induced stress, which could be useful in assessing ecological quality of estuarine ecosystems. The present study indicates that climate change mediated unusual monsoonal precipitation may notoriously affect the meiobenthic assemblages in tropical estuaries like SES. Thus, this study could be an important first stepping stone for monitoring the future environmental impact on meiobenthic community in the largest mangrove region of the world.

1. Introduction

Estuaries are considered as one of the most productive ecotone on earth (Prandle, 2009). It support invaluable ecological function and services in the context of its role in biogeochemical cycle, transport of nutrients, water purification, flux regulation of water, particles and pollutants, shoreline protection (Kennish, 2002; Alves et al., 2015). Due to its high biological productivity, estuaries forms the most important spawning zones and nursery ground for a wide variety of commercial fish and shell fish communities. Being a specialized dynamic environment, estuaries are usually well-marked by rapid variations in temperature, salinity, turbidity, dissolved oxygen and nutrient concentrations (Frontalini et al., 2014; Semprucci et al., 2014). These physicochemical variables are characterized by riverine run-off during monsoon.

Benthic communities have been conventionally used as indicators of natural and man-made environmental perturbations (Borja et al., 2000; Vanaverbeke et al., 2011; Semprucci et al., 2015a). They are considered as sensitive to any kind of natural disturbances (tide, wave, currents etc.) because they could reflect an integrated response over time. In benthic realm, meiofauna contributes a considerable amount (10^5–10^6 individuals m^{-2}) in terms of total benthic biomass (Giere, 2009). They have been used as suitable yardstick of environmental health owing to their small size, high abundance and diversity, ubiquitous distribution, rapid generation times, fast metabolic rates, direct benthic development and sessile habitat (Kennedy and Jacoby, 1999; Schratzberger et al., 2000; Balsamo et al., 2012). They are important food source for large benthic organisms (McIntyre, 1977; Gerlach, 1978; Zeppilli et al., 2015) and help in recirculation of nutrients. It has been suggested that the production of meiofauna in estuaries and shallow water bodies is much higher than those of macrofauna (Balsamo et al., 2010). Among meiofauna, free-living nematodes and harpacticoid copepods are the richest animal groups (Boucher and Lambshead, 1995; Lambshead, 2004). On account of their dominance, ubiquitousness and robust bodies make these groups of organisms promising components to study natural and anthropogenic disturbances in marine ecosystem (Sanduli and De Nicola, 1991; Bongers and Ferris, 1999; Semprucci et al., 2015b). Thorough analyses of community structure can therefore provide a

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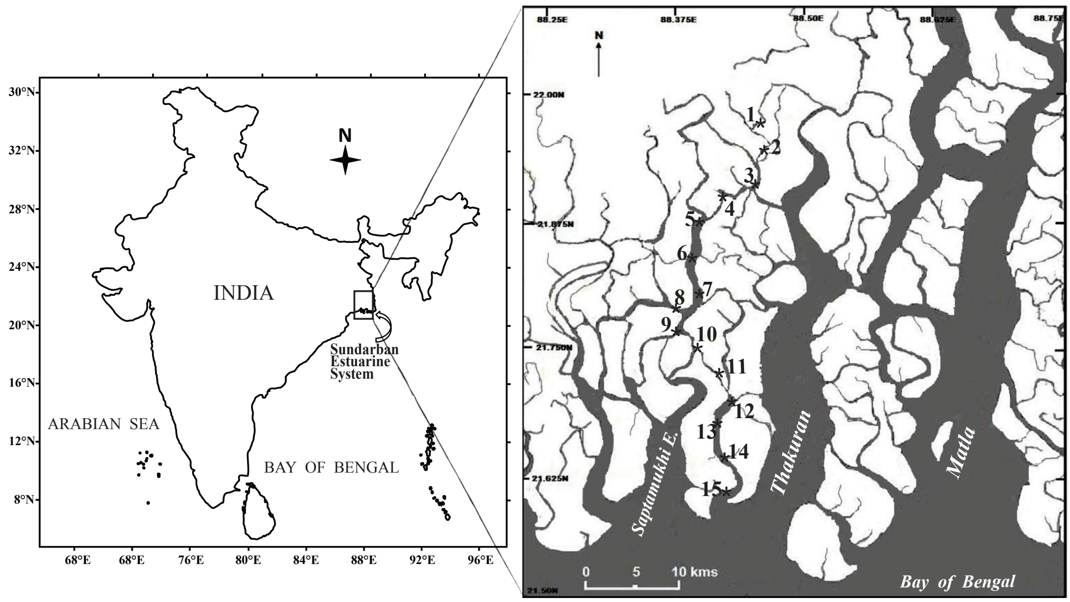

Fig. 1. Geographic location of the stations sampled in Sundarban estuarine system. All sampling stations are spread on Saptamukhi East Gulley and marked with asterisk. From S-N these are: Stations 15-11: R. Jagaddal; 10: Chaltabunia Khaal; 9-8: Curzon Creek; 7-4: R. Kaalchara; 3: Kuemari Khaal and 2-1: R. Chhatua-Raidighi.

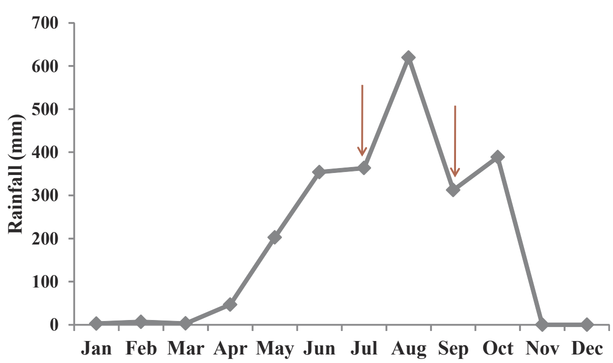

Fig. 2. Comparison of rainfall (in mm) during early (EM) and late (LM) phases of monsoon in the year 2013. Red arrows indicate sampling time. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Geographic position and name of sampling locations.

Stations	Name	Longitude	Latitude
1	Raidighi	88° 26′33.5″E	21° 59′ 23.3″N
2	Mollar Mukh	88° 27′13.9″E	21°56′38.8″N
3	Jaganath Chowk	88° 26′51.4″E	21° 54′44.61″N
4	Nandakumarpur	88° 25′1.1″E	21° 54′3.4″N
5	Nukchara Crossing	88° 24′39.2″E	21° 53′2.5″N
6	Kumarpur Junction	88° 23′31.5″E	21° 50′24.6″N
7	Birat River Crossing	88° 24′0.4″E	21° 47′58.7″N
8	Ramganga	88° 22′36.5″E	21° 47′18.3″N
9	Shibgunj	88° 23′25.2″E	21° 45′23.9″N
10	Chaltabunia Khal starting	88 °23′32.6″E	21° 44′4.3″N
11	Chapramari Ghat	88° 25′11.6″E	21° 43′15.2″N
12	Dhonchi	88° 25′50.0″E	21° 42′9.6″N
13	Between Dhonchi and Indrapur	88° 25′04″E	21°40′59″N
14	Indrapur	88° 25′13″E	21° 39′14″N
15	Bay of Bengal	88 °25′45.3″E	21° 38′14.5″N

wealth of information on the state of benthic ecosystems from intertidal to abyssal depths.

Sundarban, the largest monsoonal deltaic mangrove ecosystems of the world, is situated at the estuarine phase of the river Ganga, Bhramaputra and Meghna across India and Bangladesh (Papa et al., 2010). The complex estuarine networks are interconnecting by numerous west-east flowing channels, canals and creeks. The climate of this mangrove region is dominated by south-west (SW) monsoon (June–September) with an annual rainfall of about 1500 and 2500 mm year^{-1} (Attri and Tyagi, 2010). The monsoon period accounts for about 80 percent of the annual precipitation. Tropical mangroves forests, in general, show seasonality in precipitation. Moreover, the hydrology and physico-chemical environment are mostly governed by riverine discharge resulting from increased precipitation during monsoon (Bhattacharya et al., 2015; Venkataramana et al., 2017). On the other hand, hydrographical features play a crucial role in sedimentation pattern (Semprucci et al., 2011). Accordingly, in tropics, monsoon induced variations in hydro-climatic regimes, sedimentary environment, topography and their interactions would affect productivity of benthic communities (Alongi, 1990). Although Sundarbans is one of the well-studied estuaries in terms of water quality parameters, phytoplankton and zooplankton communities (Biswas et al., 2004; Manna et al., 2010; Bhattacharya et al., 2015), little is known regarding the effect of monsoonal run-off on the benthic ecosystem. Climate change also affected monsoon and river discharge which in turn influence regional changes (Solomon et al., 2007). Compared to last few years, SES experienced an unusual heavy rainfall during monsoon season in 2013. Furthermore, a cloud burst event occurred at the upper reaches of river Ganges (Kotal et al., 2014) in the same year which could have increased the precipitation load in manifolds at SES.

There are very few fragmented studies on meiofaunal distribution available from Sundarban (Rao and Misra, 1983; Dey et al., 2012; Ghosh et al., 2014; Sen et al., 2016). However, any comprehensive approach towards studying the ecosystem dynamics of meiofaunal populations of Sundarbans has not been attempted so far. Most ecological studies have specifically focused on seasonal variabilities of meiofauna from different habitats of Indian coasts (Ansari et al., 2001; Ingole et al., 2006; Chinnadurai and Fernando, 2007; Sajan et al., 2010; Thilagavathi et al. 2012; Datta et al., 2015), whereas intra-seasonal shift on meiobenthic diversity have not received any attention.

Against this milieu, in the present study we would like to investigate the following objectives: a) to evaluate the spatial variations in meiobenthic communities from early and later phase of monsoon, b) to

Table 2
Comparison in environmental variables during early (EM) and late (LM) phases of monsoon.

Stations	Temperature (°C)		Salinity (PSU)		pH		Dissolved oxygen (mg L^{-1})		Chl *a* (μg g^{-1})		SPM (mg L^{-1})		Organic carbon (%)		Sand (%)		Silt (%)		Clay (%)	
	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM
1	32.5	32	7.5	2	8.01	7.2	5.65	6.25	1.53	2.55	30.5	55.34	0.82	0.56	15.8	12.59	58.2	67.65	26	20.4
2	32.5	32	18	7	7.45	7.73	3.04	5.75	2.81	3.59	154	72	0.69	1.01	29.3	20.61	32.7	77.9	38	2
3	33.5	33	20	9	7.86	7.55	7.10	5.75	1.65	3.78	140.5	12	0.69	0.34	49.4	84.25	40.6	14.24	10	2
4	32.5	32	21	10	7.34	7.68	5.94	5.75	0.88	2.41	98.5	7.5	0.68	0.28	54.9	50.32	31.1	43.88	14	6.4
5	32	31.5	20	10	7.21	7.15	5.07	4.77	0.05	0.10	165.5	12.13	0.53	0.89	94.3	9.01	3.7	50.2	2	40.8
6	34	33	21.5	11.5	7.03	7.2	7.39	4.77	0.73	2.55	181.5	25.54	0.74	0.60	38.6	8.62	43.4	41.07	18	51.2
7	34.5	34	22	11.5	7.44	6.83	6.37	5.43	0.36	0.47	101.5	64.5	0.87	0.40	18.6	8.8	67.4	53.2	14	38
8	33.5	32	21	12.5	7.95	6.56	7.68	6.25	0.11	0.20	102	45.48	2.51	0.33	35.4	27.3	38.6	54.9	26	18
9	32	31	22.5	12.5	7.34	6.7	8.12	6.25	1.82	2.63	201	52.5	0.85	2.15	7.8	9.75	78.2	50.7	14	40.33
10	31.5	31	26.5	12.5	7.11	6.62	6.95	6.41	0.36	1.95	825	88.67	1.07	0.20	2.5	5.95	79.5	46.57	18	47.8
11	32.5	33	26.5	12.5	6.89	7.17	6.52	6.41	1.65	2.25	930	58.7	0.62	0.74	17.2	5.9	64.8	72.14	18	22.3
12	30	29	23	13	7.23	6.8	5.21	6.41	2.60	3.77	631	188.95	0.84	0.83	6	15.8	84	46.2	10	38
13	32	30	28	13	6.92	7.08	8.12	5.43	1.93	3.04	535	286.76	0.84	0.60	20.7	5.8	69.3	67.2	10	27
14	34.5	34	28.5	13	7.06	7.33	6.67	6.58	4.14	4.89	458	63.21	1.11	0.46	6.9	31.36	91.1	41	2	28.1
15	32	31	26	14	7.18	6.7	7.83	6.74	3.03	3.76	485	481.55	0.87	0.66	34.7	7.5	51.3	52.5	14	40

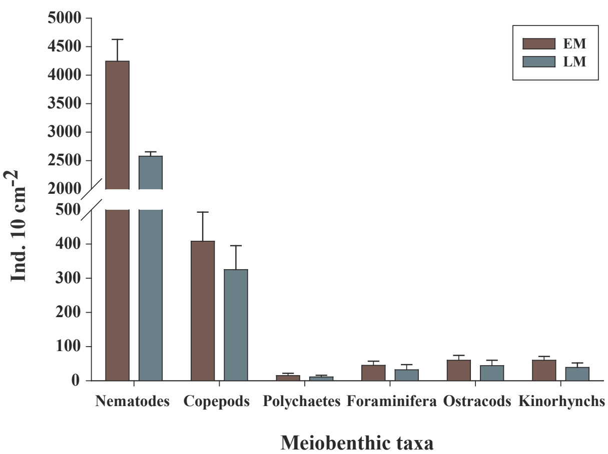

Fig. 3. Variation in meiobenthic groups during early (EM) and late (LM) phases of monsoon.

assess the influence of environmental parameters in structuring meiobenthos and c) to analyze the effect of monsoon on meiobenthic population, especially free-living nematode communities, from a tropical estuarine system, Sundarban.

2. Materials and methods

2.1. Study sites

The present investigation was conducted as part of Sundarban Estuarine Programme (SEP) during July 2013 (Early phase of monsoon) and September 2013 (Later phase of monsoon) (Fig. 1). Sampling period was chosen based on last three years' rainfall data, where in August 2013 showed highest precipitation compared to July (http://hydro.imd.gov.in/hydrometweb/(S(mgrtef55gekg2a55wkvfw5ri))/DistrictRaifall.aspx) (Fig. 2). Based on past rainfall data of this area June to October are considered major rainy seasons and more than 70% of annual precipitation normally occur during these months (Chowdhury et al., 2012). Therefore, the study was carried out to understand estuarine condition in terms of sedimentary environment and meiobenthic assemblages after unusual heavy rainfall in August 2013. The sediment samples were collected along a salinity gradient selecting 15 stations in the inner estuary of river Jagaddal, a tributary of the river Saptamukhi of the SES. The Jagaddal is an important easterly branch of the Saptamukhi East Gulley, having links with the adjoining estuary, the Thakuran, through Dhanchi Khaal, Pakhi Nala, and Shibua Gaang. The details of the sampling areas along with GPS locations are provided in Table 1.

2.2. Sample collection

Meiobenthic samples were collected in triplicate by a van Veen grab (0.04 m^2) at 15 sites. From each grab, two sub-samples were taken using a hand-held corer having an internal diameter of 5.6 cm. One core of sediment from each sub-sample was fixed immediately in 4% buffered Rose Bengal formalin. The samples were transported to the laboratory for subsequent processing and analysis. The meiofauna were identified upto group level and enumerated under a stereo zoom microscope (Magnüs MS24). Faunal numbers were expressed in number 10 cm^{-2} ± SD. From a sub-sample of each, 100 nematodes were picked randomly and mounted in a fresh drop of anhydrous glycerin on a microscopic slide for identification under a compound microscope (Nikon E200) equipped with camera using the pictorial keys (Platt and Warwick, 1983, 1988; Warwick et al., 1998) and NeMys online identification key (Bezerra et al., 2018). Nematodes were assigned to trophic groups according to the scheme of Wieser (1953) which is as follows: 1A-selective deposit feeders, 1B-non-selective deposit feeders, 2A-epistrate feeders and 2B-carnivorous/omnivorous.

Each nematode genus was classified following the classification of Bongers et al. (1991, 1995) based on colonizer-persister (c-p) scores ranging from 1 (rapid colonizer: short life cycle, high rate of egg production, high rate of metabolic activity, rapid colonizing capacity & extremely tolerable to stress) to 5 (extreme persistent: long life cycle, produce fewer eggs, most susceptible to stress). Maturity Index (MI), a life-strategy based ecosystem parameter, was calculated as weighted mean of each c-p value (Bongers, 1990). If any genus was not present in Bongers et al. (1991), family c-p value was considered.

The remaining sub-sample of each station were left untreated for organic carbon analysis by wet oxidation method using chromic acid digestion followed by titration with 0.2 N ferrous ammonium sulfate solution (El Wakeel and Riley, 1957). Percentage composition of grain size was determined following pipette analysis (Buchanan, 1984). Sediment temperature was measured using mercury thermometer during sampling. Near bottom water samples were collected by Niskin water sampler (5 L) and analyzed for pH, dissolved oxygen (DO) and salinity following standard protocols (Strickland and Parsons, 1972). Microphytobenthos was estimated as chlorophyll *a* (Chl *a*) concentration. The top first cm of sediment was cut, placed in a 15 ml polyethylene bottle and preserved in liquid nitrogen on board. Chl *a* concentration was determined with 90% acetone extraction of pigments in the laboratory

Table 3
List of free-living marine nematode species encountered in the study area during early phase of monsoon (EM) and later phase of monsoon (LM). CCA codes for nematode species are also tabulated here. '+' and '−' indicate present and absent respectively.

Species	CCA Code	Feeding type	EM	LM	c-p value
Anoplostoma viviparum (Bastian, 1865)	1	1B	+	+	2
Anticoma sp.	2	1A	+	+	2
Aponema sp.	3	1A	+	+	3
Araeolaimus elegans de Man, 1888	4	1A	+	+	3
Araeolaimus penelope Moore, 1977	5	1A	+	+	3
Araeolaimus sp.	6	1A	+	+	3
Axonolaimus paraspinosus Schuurmans Stekhoven & Adam, 1931	7	1B	+	+	2
Axonolaimus sp.	8	1B	+	+	2
Camacolaimus sp.	9	2A	+	+	3
Ceramonema sp.	10	1B	+	+	3
Chromadorella sp.	11	2A	+	+	3
Chromadora nudicapitata (Bastian, 1865)	12	2A	+	+	3
Chromadora sp.	13	2A	−	+	3
Chromadorita nana Lorenzen, 1973	14	2A	−	+	3
Chromadorita sp.	15	2A	+	+	3
Comesoma sp.	16	1B	+	+	2
Daptonema sp.	17	1B	+	+	2
Daptonema hirsutum (Vitiello, 1967)	18	1B	+	+	2
Daptonema normandicum (de Man, 1890)	19	1B	+	+	2
Desmoscolex sp.	20	1A	+	+	4
Diplolaimella sp.	21	1B	+	−	1
Doliolaimus sp.	22	2B	+	−	2
Dorylaimopsis punctata Ditlevsen, 1918	23	2A	+	+	3
Dorylaimopsis sp.	24	2A	+	+	3
Enoplus sp.	25	2B	+	+	5
Eumorpholaimus sp.	26	1B	+	−	2
Halalaimus gracilis de Man, 1888	27	1A	+	+	4
Halalaimus sp.	28	1A	+	+	4
Haliplectus dorsalis Cobb in Chitwood, 1956	29	1B	+	+	3
Leptolaimus sp.	30	1A	+	+	2
Linhystera sp.	31	1A	+	+	4
Marylynnia complexa (Warwick, 1971) Hopper, 1977	32	2A	+	+	3
Marylynnia sp.	33	2A	+	+	3
Metachromadora sp.	34	2B	+	+	2
Metalinhomoeus sp.	35	1B	+	+	2
Monhystera sp.	36	1B	+	+	1
Monoposthia costata (Bastian, 1865) de Man, 1889	37	2A	+	+	3
Monoposthia sp.	38	2A	+	+	3
Oxystomina asetosa (Southern, 1914)	39	1A	+	+	4
Paracomesoma dubium (Filipjev, 1918)	40	2A	+	+	3
Paralinhomoeus sp.	41	1B	+	+	2
Paracanthonchus sp.	42	2A	+	+	2
Paralongicyatholaimus sp.	43	2A	+	+	3
Parodontophora sp.	44	1B	+	+	1
Platycoma sp.	45	2A	+	+	3
Praeacanthonchus sp.	46	1B	+	+	4
Pselionema longiseta Ward, 1974	47	1B	+	+	3
Ptycholaimellus sp.	48	2A	+	+	3
Quadricoma sp.	49	1A	+	+	4
Quadricoma scanica (Allgén, 1935)	50	1A	+	+	4
Rhips paraornata Platt & Zhang, 1982	51	2A	+	+	3
Sabatieria bulticus	52	1B	+	+	2
Sabatieria elongata Jayasree & Warwick, 1977	53	1B	+	−	2
Sabatieria lyonessa Warwick, 1977	54	1B	+	+	2
Sabatieria praedatrix de Man, 1907	55	1B	+	+	2
Sabatieria pulchra (Schneider, 1906)	56	1B	+	+	2
Sabatieria sp.	57	1B	+	+	2
Siphonolaimus sp. de Man, 1893	58	2B	+	+	3
Sphaerolaimus balticus Schneider, 1906	59	2B	+	+	3
Sphaerolaimus sp.	60	2B	+	+	3
Terschellingia communis de Man, 1888	61	1A	+	+	3
Terschellingia longicaudata de Man, 1907	62	1A	+	+	3
Terschellingia sp.	63	1A	+	+	3
Thalassironus britannicus De Man, 1889	64	2B	+	+	3
Thalassironus sp.	65	2B	+	+	3
Theristus sp.	66	1B	+	+	2
Tricoma brevirostris (Southern, 1914)	67	1A	+	+	4
Tricoma sp.	68	1A	+	+	4
Vasostoma sp.	69	1A	+	+	4
Viscosia abyssorum (Allgén, 1933) Warwick & Buchanon, 1970	70	2B	+	+	3
Viscosia cobbi Filipjev, 1918	71	2B	+	+	3
Viscosia sp.	72	2B	+	+	3

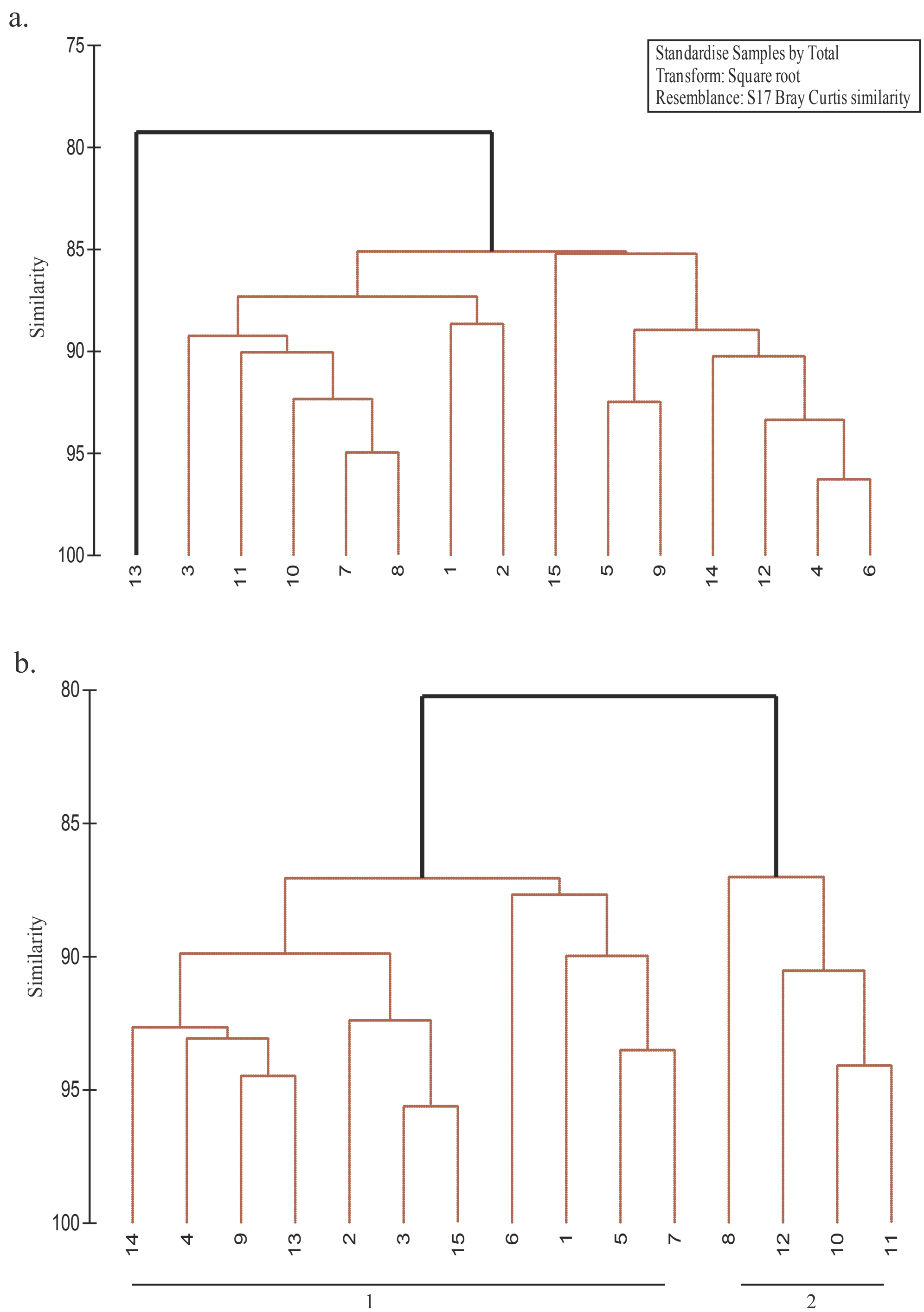

Fig. 4. Cluster plot based on Bray–Curtis similarity coefficient of meiobenthic species during two different phases of sampling periods: a. EM and b. LM. After SIMPROF test, the main groups of stations can be identified by dark black lines.

following standard formulae (Strickland and Parsons, 1972). Suspended particulate matter (SPM) contents were estimated as dry weight (60 °C, 24 h) *in vitro* after filtration of 5 L water samples through pre-weighed nitrocellulose membrane filters (Harrison et al., 1997).

2.3. Data analysis

Univariate and multivariate analyses of data were performed using PRIMER version 6 (Plymouth Routines in Multivariate Ecological Research; Clarke and Gorley, 2006; Clarke et al., 2008) with PERMANOVA add-on package (Anderson et al., 2008). Non-multidimensional scaling (NMDS) and Bray–Curtis similarity index were constructed based on meiofaunal abundance after square-root transformation. A similarity profile (SIMPROF) test was conducted to detect the significantly different station groups using the default of 1000 permutations for the mean similarity profile and 999 permutations for the simulated profile with a significance level of 0.05. Similarity of percentages analysis (SIMPER) was carried out to identify the major species which represented groups and those most responsible species for the discrimination between groups. The following indices were determined based on nematode density: Shannon diversity (H′), Margalef's species richness (d), Pielou's evenness (J′) and Simpson index

Table 4
Results of two-factor PERMANOVA analysis ("station" and "season" as fixed factors) for community composition of total meiofauna and nematode ($p < 0.05$).

	Source	Degrees of freedom	Sum of sqares	Mean squares	Pseudo-F	P (perm)
Total meiofauna	Station	14	3922.4	280.17	41.696	0.001
	Season	1	2270.5	2270.5	337.9	0.001
	Station x Season	14	3857.8	275.56	41.01	0.001
	Residual	60	403.16	6.7194		
	Total	89	10454			
Total nematode density	Station	14	4655	332.5	34.695	0.001
	Season	1	2588.6	2588.6	270.11	0.001
	Station x Season	14	4866.6	347.61	36.272	0.001
	Residual	60	575.01	9.5834		
	Total	89	12685			

$(1 - \lambda')$. A two-way ANOVA (analysis of variance) was done to check the significant spatial and temporal variation of meiofauna as well as nematode communities. To investigate the role of seasonal and temporal effect on total meiofaunal abundance were analyzed through two-way Permutational Multivariate Analysis of Variance (PERMANOVA) with station as first factor (15 stations) and season as a second factor (early monsoon and late monsoon). All PERMANOVA test were done on Bray-Curtis similarity matrices using permutation of residuals under a reduced model, with 999 permutations.

To evaluate the relationship between the nematode community and environmental variables, canonical correspondence analysis (CCA) (ter Braak, 1986) was applied using the Multivariate Statistical Package (MVSP) program version 3.1 (Kovach, 1998).

3. Results

3.1. Environmental parameters

The environmental parameters measured from bottom water and sediment showed significant variations between two phases of season (t – test, $p < 0.05$; except pH, dissolve oxygen, organic carbon, sand and silt fraction of sediment; Table 2). Bottom water salinity showed an increasing trend from fresh water towards Bay of Bengal throughout the study areas in both seasons. Salinity values ranged from 7.5 PSU to 26 PSU in early phase of monsoon (EM) and after exceptionally high precipitation in August, salinity dropped and ranged from 2 PSU to 14 PSU in later phase of monsoon (LM). The pH value showed more or less alkaline in nature. It varied between 6.89–8.01 and 6.56–7.73 in EM and LM respectively. EM showed the lowest average DO value ($5.93\ mg\ L^{-1}$) compared to the LM ($6.51\ mg\ L^{-1}$). The value of Chl *a* ranged from 0.05 to 4.14 μg^{-g} and 0.10–4.89 μg^{-g} during EM and LM respectively.

The sediment texture was characterized by silt-clay or clay at all sites in both the seasons except station 5 of EM where the sediment is sandy in nature. Silt and clay percentage varied between 3.7–91.1 and 2–47.8 respectively during both seasons. The percentage organic carbon content ranged from 0.20 (station 10 in LM) to 2.51 (station 8 in EM).

3.2. Meiobenthic communities

Total meiobenthic density revealed significant differences between two phases of monsoon (ANOVA: $p < 0.05$). A total of six major meiofaunal taxa were found from both seasons, namely nematodes, harpacticoid copepods, polychaetes, foraminifera, ostracods and kinorhynchs. The average meiofaunal abundances in the fifteen stations varied between 699 ± 1569.4 ind. $10\ cm^{-2}$ and 437 ± 949.9 ind. $10\ cm^{-2}$ during EM and LM respectively (Fig. 3). During EM minimum average meiofaunal density (310 ± 651.1 ind. $10\ cm^{-2}$) was observed at station 15 and maximum (1304 ± 2980.9 ind. $10\ cm^{-2}$) at station 14. Similarly, during LM minimum average meiofaunal density (203 ± 362.3 ind. $10\ cm^{-2}$) was observed at station 12 and maximum (781 ± 1905.3 ind. $10\ cm^{-2}$) at station 14. Free-living nematodes were the dominant taxonomic group in both the seasons (87.76% and 84.22% of total meiofauna in EM and LM respectively). In EM and LM, nematodes were followed in abundance by harpacticoid copepods (8.34% and 10.62% respectively). The other taxa were polychaetes (0.31% and 0.36%), foraminifera (0.92% and 1.05%), ostracods (1.23% and 1.44%) and kinorhynchs (1.23% and 1.27%).

3.3. Nematode assemblages

A total of 72 species belonging to 49 genera, 22 families and 7 orders were identified during both phases of monsoon. Among these, 4 species belonging to 4 families were recorded from early monsoon season and 2 species belonging to 1 family from late monsoon exclusively. The highest abundance was observed in EM (8033 ± 166 ind. $10\ cm^{-2}$) in comparison with the abundance in LM (5099 ± 250 ind. $10\ cm^{-2}$). Two way ANOVA on total nematofaunal density detected significant variation (ANOVA: $p < 0.05$) between two phases of monsoon (EM and LM), whereas there were no significant differences between sampling sites (15 stations).

The dominant families in both seasons were Comesomatidae, Chromadoridae, Linhomoeidae and Xylidae. Among the 22 families encountered, 7 were represented by a single genus. The family Comesomatidae was represented by five genera namely *Comesoma*, *Dorylaimopsis*, *Paracomesoma*, *Sabatieria* and *Vasostoma*. The families Chromadoridae, Linhomoeidae and Xylidae were represented by five, four and three genera respectively. The genus *Sabatieria* was represented by six species. The trophic structure revealed a community dominated by non-selective deposit feeders (1B) during both phases of monsoon followed by selective deposit feeders (1A), predators/omnivores (2B) and epigrowth feeders (2A). All kind of colonizer-persister groups (c-p 1 to 5) were present in both monsoon phases. However, c-p 3 group (47.14% & 50% in EM & LM respectively) was significantly more abundant followed by c-p 2 (31.40% & 27.14% in EM & LM respectively) and c-p 4 (15.71% & 2.85% in EM & LM respectively) groups across the stations. MI values ranged from 2.53 (station 7) to 3.00 (station 2) and 2.38 (station 2) to 3.03 (station 9) in early and late monsoon respectively. A complete list of the species identified from both phases of monsoon is provided in Table 3.

3.4. Statistical analysis

Fig. 3 revealed a significant difference in abundance of meiobenthic taxa in both seasons (*t*-test < 0.05; except copepod). Cluster analyses

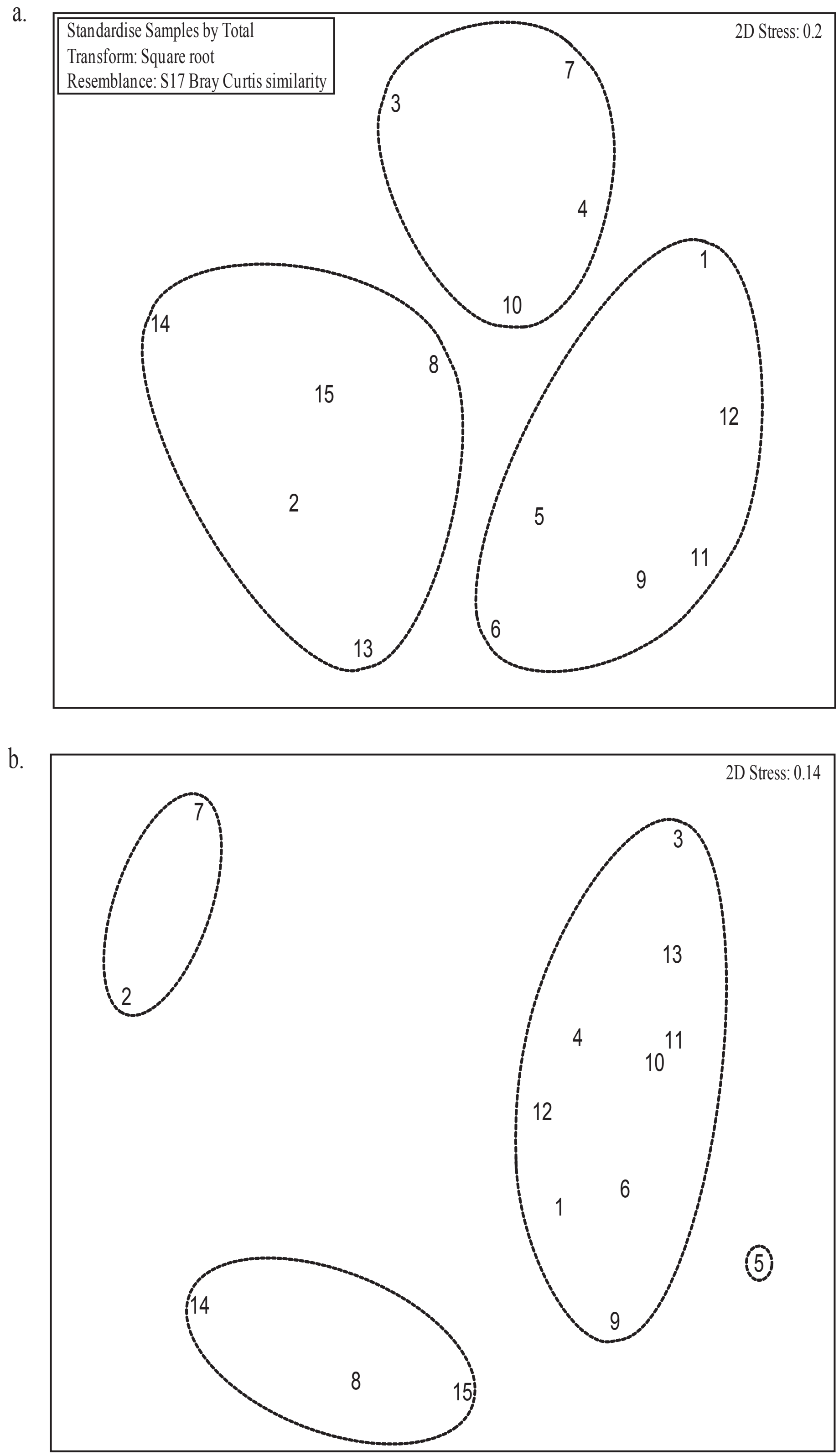

Fig. 5. NMDS (non-metric multidimensional scaling) ordination plot of free-living marine nematode community based on square-root transformed data for two phases of monsoon: a. EM and b. LM.

of the Bray–Curtis similarity matrix based on meiobenthic taxa delineated one large group and one separate station (SIMPROF test $p < 0.05$) during EM (Fig. 4a). All stations, except station 13 were grouped together to form that group. SIMPER analysis showed that nematodes contributed 54.96% the group among the other meiofaunal taxa. During LM, two groups were identified in the cluster analyses (Fig. 4b). SIMPROF analysis showed group 1 was the most significant (87.07%) between the two groups during that season. Group 1 had the highest number of stations and species dominance. SIMPER analysis indicated that nematodes contributed remarkably in group 1 (61.72%)

Table 5
Variation in benthic community indices for all stations during EM and LM. S = total number of species, N = total population density per meter square, d = species richness (Margalef), J′ = Pielou's evenness, H′ = Shannon index, 1 − λ′ Simpson index.

Stations	S		N		d		J′		H′(loge)		1 − λ′	
	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM	EM	LM
1	36	24	100	100	7.60	4.99	0.85	0.86	3.06	2.74	0.94	0.90
2	27	8	100	100	5.65	1.52	0.89	0.72	2.92	1.50	0.93	0.69
3	40	34	100	100	8.47	7.17	0.89	0.86	3.29	3.03	0.95	0.93
4	35	33	100	100	7.38	6.95	0.89	0.92	3.15	3.20	0.95	0.95
5	31	28	100	100	6.51	5.86	0.90	0.92	3.10	3.05	0.94	0.95
6	37	36	100	100	7.82	7.60	0.90	0.89	3.26	3.17	0.95	0.94
7	38	11	100	100	8.03	2.17	0.96	0.68	3.48	1.63	0.97	0.71
8	34	17	100	100	7.17	3.47	0.88	0.62	3.10	1.77	0.94	0.67
9	32	33	100	100	6.73	6.95	0.88	0.85	3.03	2.97	0.94	0.93
10	39	38	100	100	8.25	8.03	0.90	0.89	3.28	3.23	0.95	0.95
11	36	38	100	100	7.60	8.03	0.88	0.90	3.17	3.27	0.94	0.95
12	41	29	100	100	8.69	6.08	0.93	0.91	3.45	3.05	0.97	0.95
13	35	32	100	100	7.38	6.73	0.89	0.89	3.17	3.08	0.95	0.95
14	22	9	100	100	4.56	1.74	0.92	0.63	2.86	1.38	0.94	0.67
15	33	20	100	100	6.95	4.13	0.89	0.80	3.10	2.40	0.95	0.87

and group 2 (44.85%) correspondingly. PERMANOVA analysis of total meiofaunal and nematode density data indicated a significant interaction between "station" and "season" ($p < 0.05$; Table 4).

NMDS plot based on nematode species data clearly reflected certain grouping of stations in each season. In EM, (based on 53% similarity) three groups were formed indicating variation in nematode species composition (Fig. 5a). SIMPER analysis indicated that *Sabatieria* sp. alone contributed 12.87%, 9.87% and 11.73% in formation of group 1, 2 and 3 respectively. Similarly, NMDS plot from LM (based on 46% similarity) showed three distinct groups and one separate station (Fig. 5b). Presence of carnivorous nematode genus *Metachromadora* in station 5 separated it from other groups.

Significant variations were observed between two phases of season by the diversity indices (t – test, $p < 0.05$; d, J′, H′ and 1 − λ′). Margalef's species richness (d) ranged from 4.56 to 8.69 and 1.52 to 8.03 during EM and LM respectively. Shannon diversity index (H′) ranged between 2.86 bit·ind^{-1} to 3.48 bit·ind^{-1} in EM and 1.38 bit·ind^{-1} to 3.27 bit·ind^{-1} in LM. In later phase of monsoon (LM), Shannon diversity values had below two bit·ind^{-1} (Stations 2, 7, 8 and 14). Pielou's evenness (J′) values were more or less similar at all stations in both seasons (Table 5).

In the CCA biplot for nematode species, the five axes represented that 70.38% relationship between nematode species and environmental variables (Fig. 6a). Chlorophyll content (Chl *a*), sediment texture, organic carbon, salinity and SPM were the most significant controlling factors in shaping the nematode communities in both seasons. It was observed that different nematode species showed preference towards specific environmental parameters. Selective deposit feeder nematode species *Desmoscolex* sp., *Oxystomina asetosa*, *Quadricoma scanica*, *Tricoma brevirostris* and non-selective deposit feeder species *Axonolaimus* sp., *Daptonema* sp., *Monhystera* sp., *Paralinhomoeus* sp., *Sabatieria pulchra* showed preference towards organic carbon content of sediment. High densities of these species were observed in stations with high organic carbon content. Selective deposit feeding species *Araeolaimus penelope*, *Desmoscolex* sp.; non-selective deposit feeding species *Anoplostoma viviparum*, *Axonolaimus paraspinosus*, *Daptonema hirsutum* and epistrate feeder *Chromadorita nana* were associated with clayey substratum of sediment. Selective deposit feeding nematode *Terschellingia longicaudata*, *Tricoma* sp. and *Vasostoma* sp.; non-selective deposit feeder *Theristus* sp., one epistrate feeder *Paracomesoma dubium* and one carnivorous species *Sphaerolaimus* sp. profited by sandy and silty sediment texture. *Platycoma* sp., *Rhips paraornata* and *Sabatieria lyonessa* favored elevated salinity. *Chomadorita* sp., *Chromadora nudicapitata*, *Diplolaimella* sp., *Enoplus* sp., and *Metachromadora* sp. were not influenced by any other environmental factors. In station biplot (Fig. 6b), seasonal patterns were also prominent. During EM, station 7 and 8 were associated with organic carbon; station 4 and 9 and station 5 were influenced by SPM and salinity respectively; stations 2 and 3 and stations 6 were linked with temperature and pH of sediment respectively. During LM, stations 3, 11 and 13 and station 4 were associated with sand and silt fraction of sediment respectively; station 6, 7 and 12 were influenced by clay; station 14 was linked with higher chlorophyll content of sediment. In EM and LM, station 1, 10, 11, 12 and 14 and station 1, 2, 5, and 10 respectively were separated from environmental variables. Nematode species *Axonolaimus*, *Daptonema*, *Quadricoma* and *Sabatieria* were found dominant from these stations.

4. Discussion

In estuaries, horizontal distribution of meiofauna is governed by biotic and abiotic factors (Gallucci et al., 2008; Ferrero et al., 2008). A significant temporal variation was observed in the environmental parameters between two phases of monsoon (Table 2). The variation in the environmental parameters was due to the SW monsoon mediated river discharge. A sharp decline in bottom water salinity from early to later phase of monsoon was clearly observed. The drop in salinity level during later phase might be attributed to the riverine runoff that completely flushed the estuary. During 2013, there was unusual high rainfall (619.6 mm) in August, which was much higher than July (363.3 mm) (Fig. 2). Furthermore, in June 2013, a devastating cloud burst phenomenon took place at the upper Himalayan territories of Himachal Pradesh and Uttarakhand of India, which might exacerbate heavy runoff at Sundarban deltatic system (Kotal et al., 2014). The variation in the physico-chemical parameters due to the effect of the annual monsoon as preceded by cloud burst event in that year also influenced the meiobenthic assemblages of Sundarban. Average meiobenthic abundance declined considerably in the study area from early (EM) (699 ± 1569.4 ind. 10 cm^{-2}) to later phase of monsoon (LM) (437 ± 949.9 ind. 10 cm^{-2}). A decline in species composition in the soft sediments of estuaries from the sea to freshwater is a general trend of global estuarine system (Austen et al., 1994; Giménez et al., 2005). However, in present study, meiofauna distribution did not closely follow any estuarine gradient. Similar observations were also reported from a coastal lagoon of southern Italy (Frontalini et al., 2014; Semprucci et al., 2014). The meiofaunal composition, obtained in our results, was similar to that observed in the sub-tidal area of estuarine system (Alves et al., 2013) with a dominance of free-living nematode community. Nematodes generally dominate meiobenthic organisms with harpacticoid copepods ranking second, the most usual pattern observed in tropical estuaries (Coull, 1999).

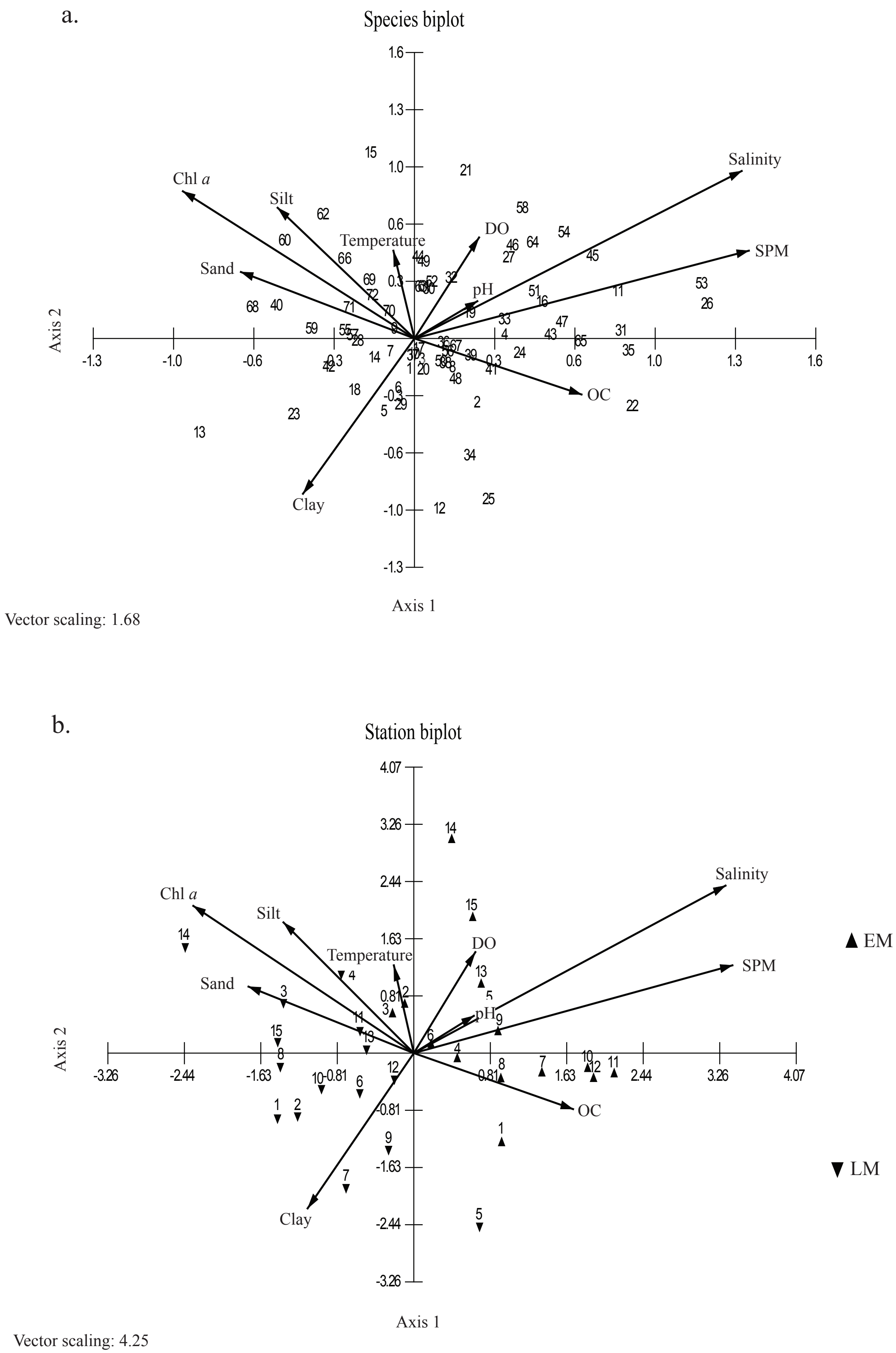

Fig. 6. Ordination diagrams for a. species and b. stations based on canonical corresponding analysis (CCA) of free-living nematode community. The environmental variables (Temperature, pH, dissolved oxygen, salinity, Chl *a*, SPM, sand, silt, clay, organic carbon) are indicated by arrows. Species codes are given in Table 3.

In early phase of monsoon, nematode abundance was unusually higher at station 13 and 14 than other sites (11.7% and 12.6% of total nematodes respectively). There was a fish landing center in between these two stations. These areas were generally important source of soluble organic carbon (Pearson and Black, 2001), which progressively transform the substrate into an anoxic environment (Holmer et al., 2003) and support r selected species abundance. Furthermore, higher organic carbon might be beneficial for deposit feeding groups of nematode. This could be one of the reasons behind higher nematode abundance as reflected by few deposit feeding species particularly those stations.

Few nematodes play an overriding role in shaping nematofaunal community of study areas. Dominance of opportunistic taxa like, *Sabatieria* and *Daptonema* (c-p 2) were recorded from both phases of monsoon (Sandulli et al., 2014; Chen et al., 2018). Species of these genera appear to be tolerant of a wide range of environmental perturbation and are frequently reported from disturbed habitats worldwide (Heip et al., 1985, 1990; Somerfield et al., 1995). *Sabatieria* is a typical representative of muddy sediments all over the world and many of its species are considered as tolerant to polluted environments (Steyaert et al., 1999). In EM, station 2 is highly colonized by *Sabatieria*, because of its ability to tolerate anoxic environment, as mirrored by lower bottom DO at that station. Being a non-selective deposit feeder, *Sabatieria* is well adapted to disturbed conditions of sediment (Vanreusel, 1990; Landers et al., 2014). Nematodes are generally considered as more resilient to any kind of physical disturbance than macrofauna as they can recover more quickly (Schratzberger et al., 2002). Sediment grain size (Vanaverbeke et al., 2011; Semprucci et al., 2010, 2016) and quantity of organic carbon (Ingels et al., 2009; Pusceddu et al, 2011) are fundamental factors that could determine biodiversity and abundance of meiofauna and nematode communities. The association between silt and clay portion of sediment and organic carbon are reported in many literatures (Neira et al., 2001; Bernardello et al., 2006; Sutherland et al., 2007; Semprucci et al 2016) as silt and clay particles could adsorb the organic pollutants. This is in accordance with present study. During EM, higher abundance of nematode in station 14 was positively associated with higher percentage of silt and organic carbon, while nematode remained abundant at station 14 during LM period also (Table 2). Most of the sampling stations were dominated by nematode genera like *Sabatieria*, *Theristus*, *Viscosia*, *Daptonema*, *Terschellingia*, *Metalinhomoeus* which are typical representatives of fine sediments (Heip et al., 1985; Sandulli et al., 2014; Boufahja et al. 2016). They are non-selective deposit feeders (except *Viscosia* and *Terschellingia*) and are dominant trophic group in muddy sediments rich in organic matter (Michiels and Traunspurger, 2004; Adão et al., 2009).

Different feeding guilds of nematode could be used as an indicator of benthic environment which generally differ due to food availability (Santos et al., 2008). Selective (1A) and non-selective deposit feeders (1B) generally dominate in the homogeneous mud habitats (Giere, 2009). There are many studies explaining the significant role of food availability and sediment properties on spatial distribution, abundance and species composition of free-living nematodes (Heip et al., 1985; Austen and Warwick, 1989; Balsamo et al., 2010). Our study is in agreement with those reports. For example, epigrowth feeding nematode *Camacolaimus* sp. and omnivorous species *Viscosia cobbi* were associated with Chl *a* as benthic diatom was an important food source for epigrowth feeders (Moens and Vincx, 1997). Epigrowth feeding nematode, like *Camacolaimus* sp. was influenced by Chl *a* (Fig. 6a) as benthic diatom was an important ration for epigrowth feeders (Moens and Vincx, 1997).

India receives majority of its rainfall during summer monsoon, which accounts more than 80% of the total annual precipitation (Bollasina, 2014). Intra-seasonal variability of rainfall can have disastrous effects on ecosystem functioning. Human induced climate changes have been evident in Indian monsoon precipitation (Annamalai and Sperber, 2016). Moreover, in recent years altered climatic condition has profound impact on annual rainfall patterns and intensity, which in turn cause various natural calamities, including intense rainfall events, cyclones, cloud burst and flash flood. In his seminal paper, Alongi (1990) documented tropical benthic fauna has been synchronized and affected by monsoonal rainfall. An alteration in rainfall patterns may have detrimental impact on benthic realm (Przeslawski et al., 2008). As meiobenthic organisms lack planktonic larval stages and have direct benthic development, the juveniles as well as adults are more susceptible to such physical disturbances caused by the monsoonal wash off. Monsoon periods are generally considered as spawning time for most of the tropical benthic organisms and they release their progeny stimulated by salinity drop (Broom, 1982; Kinne, 1977). Due to high nutrient load, late monsoon period generally characterized by high primary productivity (Madhu et al., 2007) which act as ample food resources for early recruiters. Therefore, change in natural monsoonal precipitation along with catastrophic events may have deleterious effect on overall distribution of entire meiobenthic population (Altaff et al., 2005; Fattorini et al., 2018).

Thus, the analyses of the sub tidal meiobenthic communities of the SES, with special emphasis on free-living nematodes, are the first attempt to fill the gap of knowledge regarding the distribution of these communities. Our results provide a general picture of how the unusual heavy precipitation influenced the spatial distribution of meiofauna and nematodes. Hence, further studies are needed to unmask the benthic community structure controlled by environmental perturbations from the world's largest ecosystem. Sundarban is an ecologically and economically important estuarine system; hence to understand the natural variation as well as changes caused by anthropogenic perturbation is need of the hour. Meiofauna can give important insights regarding pollution monitoring process and free-living nematode communities have also progressively been used to evaluate the effects of environmental disturbances (Gyedu-Ababio et al., 1999; Guo et al., 2001).

5. Conclusion

SW monsoon induced environmental changes has tremendous effect in shaping meiobenthic community in SES. The unusual heavy rainfall in 2013 has decreased the abundance of meiobenthic community. Moreover, present study can help to understand the natural variations in meiobenthic communities present in this ecosystem along with its changes caused by climate change mediated unusual rainfall. Thus, the estimation of the benthic biodiversity, using meiobenthos as proxy, of this area is urgent for evaluation of the ecological quality of the sediments. Therefore, the result of this study can be as baseline information for community structure of SES. Further benthocosm experiments are needed to unravel the intricate dynamics of benthic ecosystem in future climate change scenario at SES.

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References

Adão, H., Alves, A., Patrício, J., Neto, J.M., Costa, M.J., Marques, J.C., 2009. Spatial distribution of subtidal Nematoda communities along the salinity gradient in two Southern European estuaries (Portugal). Acta Oecol. 35, 287–300.

Alongi, D.M., 1990. The ecology of tropical soft-bottom benthic ecosystem. Oceanogr. Mar. Biol. Annu. Rev. 28, 381–496.

Alves, A.S., Adão, H., Ferrero, T.J., Marques, J.C., Costa, M.J., Patrício, J., 2013. Benthic meiofauna as indicator of ecological changes in estuarine ecosystems: the use of nematodes in ecological quality assessment. Ecol. Indic. 24, 462–475.

Alves, A.S., Caetano, A., Costa, J.L., Costa, M.J., Marques, J.C., 2015. Estuarine intertidal meiofauna and nematode communities as indicator of ecosystem's recovery following mitigation measures. Ecol. Indic. 54, 184–196.

Altaff, K., Sugumaran, J., Naveed, Md.S., 2005. Impact of tsunami on meiofauna of Marina Beach, Chennai, India. Curr. Sci. 89 (1), 34–38.

Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA A+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK.

Annamalai, H., Sperber, K.R., 2016. South Asian summer monsoon variability in a changing climate. In: de Carvalho, L., Jones, C. (Eds.), The Monsoons and Climate Change. Springer Climate, Springer, Cham.

Ansari, A., Rivonkar, C.U., Sangodkar, U.M., 2001. Population fluctuation and vertical distribution of meiofauna in a tropical mudflat at Mandovi estuary, west coast of India. Indian J. Mar. Sci. 30, 237–245.

Attri, S.D., Tyagi, A., 2010. Climate Profile of India; Met. Monograph No. Environment Meteorology – 01/2010. India Meteorological Department, Ministry of Earth Sciences, Government of India, 129p.

Austen, M.C., Warwick, R.M., 1989. Comparison of univariate and multivariate aspects of estuarine meiobenthic community structure. Estuar. Coast. Shelf Sci. 29, 23–42.

Austen, M.C., McEvoy, A.J., Warwick, R.M., 1994. The specificity of meiobenthic community response to different pollutants: results from microcosm experiments. Mar. Pollut. Bull. 28, 557–563.

Balsamo, M., Albertelli, G., Ceccherelli, V.U., Coccioni, R., Colangelo, M.A., et al., 2010. Meiofauna of the Adriatic Sea: current state of knowledge and future perspective. Chem. Ecol. 26, 45–63.

Balsamo, M., Semprucci, F., Frontalini, F., Coccioni, R., 2012. Meiofauna as a tool for marine ecosystem biomonitoring. In: Cruzado, A. (Ed.), Marine Ecosystems. In Tech Publisher, Rijeka, pp. 77–104.

Bernardello, M., Secco, T., Pellizzato, F., 2006. The changing state of contamination in the lagoon of Venice. Part 2: Heavy metals. Chemosphere 64, 1334–1345.

Bezerra, T.N., Decraemer, W., Eisendle-Flöckner, U., Holovachov, O., Leduc, D., Miljutin, D., Sharma, J., Smol, N., Tchesunov, A., Mokievsky, V., Venekey, V., Vanreusel, A., 2018. NeMys: World Database of Free-Living Marine Nematodes. Accessed at http://nemys.ugent.be on 2018-04-06.

Bhattacharya, B.D., Hwang, J.-S., Sarkar, S.K., Rakhsit, D., Murugan, K., Tseng, L.-C., 2015. Community structure of mesozooplankton in coastal waters of Sundarban mangrove wetland, India: a multivariate approach. J. Mar. Syst. 141, 112–121.

Biswas, H., Mukhopadhyay, S.K., De, T.K., Sen, S., Jana, T.K., 2004. Biogenic controls on the air-water carbon dioxide exchange in the Sundarban mangrove environment, northeast coast of Bay of Bengal, India. Limnol. Oceanogr. 49, 95–101.

Bollasina, M.A., 2014. Hydrology: probing the monsoon pulse. Nat. Clim. Change 4, 422–423.

Bongers, T., 1990. The maturity index: an ecological measure of environmental disturbance based on nematode species composition. Oecologia 83, 14–19.

Bongers, T., Alkemade, R., Yeates, G.W., 1991. Interpretation of disturbance-induced maturity decrease in marine nematode assemblages by means of the Maturity Index. Mar. Ecol. Prog. Ser. 76, 135–142.

Bongers, T., de Goede, R.G.M., Korthals, G.W., Yeates, G.W., 1995. Proposed changes of c-p classification for nematodes. Russ. J. Nematol. 3 (1), 61–62.

Bongers, T., Ferris, H., 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends Ecol. Evol. 14, 224–228.

Borja, A., Franco, J., Pérez, V., 2000. A marine biotic index to establish the ecological quality of soft bottom benthos within European estuarine and coastal environments. Marine Poll. Bull. 40, 1100–1114.

Boucher, G., Lambshead, P.J.D., 1995. Ecological biodiversity of marine nematodes in samples from temperate, tropical and deep-sea regions. Conserv. Biol. 9, 1594–1604.

Boufahja, F., Semprucci, F., Beyrem, H., 2016. An experimental protocol to select nematode species from an entire community using progressive sedimentary enrichment. Ecol. Ind. 60, 292–309.

Broom, M.J., 1982. Structure and seasonality in a Malaysia mudflat community. Estuar. Coast. Shelf Sci. 15, 135–150.

Buchanan, J.B., 1984. Sediment analysis. In: Holme, N.A., McIntyre, A.D. (Eds.), Methods for the Study of Marine Benthos. Oxford Blackwell Scientific Publications, pp. 41–65.

Chen, C.A., Soo, C.L., Balsamo, M., Semprucci, F., 2018. An approach based on nematode descriptors for the classification of ecological quality (EcoQ) of the Malaysian coasts. Mar. Biodiv. 48 (1), 117–126.

Chinnadurai, G., Fernando, O.J., 2007. Meiofauna of mangroves of the southeast coast of India with special reference to the free-living marine nematode assemblage. Estuar. Coast. Shelf Sci. 72, 329–336.

Chowdhury, C., Majumder, N., Ray, R., Jana, T.K., 2012. Inter-annual abundance variation in some genera of diatom and zooplankton in mangrove ecosystem. Biodivers. Conserv. 21 (8), 2029–2043.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., Somerfield, P.J., Chapman, M.G., 2008. Testing of null hypotheses in explanatory community analyses: Similarity profiles and biota-environment linkage. J. Exp. Mar. Biol. Ecol. 366, 56–69.

Coull, B.C., 1999. Role of meiofauna in estuarine soft-bottom habitats. Aust. J. Ecol. 24, 327–343.

Datta, T.K., Navarrete, A.D.J., Mahapatro, A., 2015. *Rhynchonema dighaensis* sp. nov. (Monhysterida: Xyalidae): a marine nematode from the Indian coast with an illustrated guide and modified key for species of *Rhynchonema* Cobb, 1920. Zootaxa 3905 (3), 365–380.

Dey, M., Ganguly, D., Chowdhury, C., Majumder, N., Jana, T.K., 2012. Intra-annual variation of modern foraminiferal assemblage in a tropical mangrove ecosystem. Wetlands 32 (5), 813–826.

El Wakeel, S.K., Riley, J.P., 1957. The determination of organic carbon in the marine muds. ICES J. Mar. Sci. 22 (2), 180–183.

Fattorini, S., Lorenzo, T. Di., Galassi, D.M.P., 2018. Earthquake impacts on microcrustacean communities inhabiting groundwater-fed springs alter species-abundance distribution patterns. Sci. Rep. 8 (1), 1501. http://dx.doi.org/10.1038/s41598-018-20011-1.

Ferrero, T.J., Debenham, N.J., Lambshead, P.J.D., 2008. The nematodes of the Thames estuary: assemblage structure and biodiversity, with a test of Attrill'slinear model. Estuar. Coast. Shelf Sci. 79, 409–418.

Frontalini, F., Semprucci, F., Armynot du Châtelet, E., Francescangeli, F., Margaritelli, G., Rettori, R., Spagnoli, F., Balsamo, M., Coccioni, R., 2014. Biodiversity trends of the meiofauna and foraminifera assemblages of Lake Varano (southern Italy). Proc. Biol. Soc. Wash. 127, 7–22.

Gallucci, F., Moens, T., Vanreusel, A., Fonseca, G., 2008. Active colonization of disturbed sediments by deep-sea nematodes: evidence for the patch mosaic model. Mar. Ecol. Prog. Ser. 367, 173–183.

Gerlach, S.A., 1978. Food chain relationship in subtidal silty sand marine sediment and the role of meiofauna in stimulating bacterial productivity. Oecologia 33, 55–69.

Ghosh, A., Biswas, S., Barman, P., 2014. Marsh foraminiferal assemblages in relation to vegetation in Sunderban, India. J. Geol. Soc. India 84, 657–667.

Giere, O., 2009. Meiobenthology: The Microscopic Motile Fauna of Aquatic Sediments, second ed. Springer, Berlin, Heidelberg.

Giménez, L., Borthagaray, A.E., Rodríguez, M., Brazeiro, A., Dimitriadis, C., 2005. Scale-dependent patterns of macrofaunal distribution in soft-sediment intertidal habitats along a large-scale estuarine gradient. Helgol. Mar. Res. 59, 224–236.

Guo, Y., Somerfield, P.J., Warwick, R.M., Zhang, Z., 2001. Large-scale patterns in the community structure and biodiversity of free-living nematodes in the Bohai Sea, China. J. Mar. Biol. Assoc. U.K. 81, 755–763.

Gyedu-Ababio, T.K., Furstenberg, J.P., Baird, D., Vanreusel, A., 1999. Nematodes as indicators of pollution: a case study from the Swartkops River system, South Africa. Hydrobiologia 397, 155–169.

Harrison, P.J., Khan, N., Yin, K., Saleem, M., Bano, N., Nisa, M., Ahmed, S.I., Rizvi, N., Azam, F., 1997. Nutrient and phytoplankton dynamics in two mangrove tidal creeks of the Indus river delta Pakistan. Mar. Ecol. Prog. Ser. 157, 13–19.

Heip, C., Vincx, M., Vranken, G., 1985. The ecology of marine nematodes. Oceanogr. Mar. Biol. Annu. Rev. 23, 399–489.

Heip, C., Huys, R., Vincx, M., Vanreusel, A., Smol, N., Herman, R., Herman, P.M.J., 1990. Composition, distribution, biomass and production of North Sea meiofauna. Neth. J. Sea Res. 26, 333–342.

Holmer, M., Duarte, C.M., Heilskov, A., Olesen, B., Terrados, J., 2003. Biogeochemical conditions in sediments enriched by organic matter from net-pen fish farms in the Bolinao area, Philippines. Marine Poll. Bull. 46, 1470–1479.

Ingels, J., Kiriakoulakis, K., Wolff, G.A., Vanreusel, A., 2009. Nematode diversity and its relation to the quantity and quality of sedimentary organic matter in the deep Nazaré Canyon, Western IberianMargin. Deep-Sea Res. Part I 56, 1521–1539.

Ingole, B., Sivadas, S., Goltekar, R., Clemente, S., Nanajkar, M., Sawant, R., D'Silva, C., Sarkar, A., Ansari, Z., 2006. Ecotoxicological effect of grounded MV River Princess on the intertidal benthic organisms off Goa. Environ. Int. 32, 284–291.

Kennedy, A.D., Jacoby, C.A., 1999. Biological indicators of marine environmental health: meiofauna – a neglected benthic component? Environ. Monit. Assess. 54 (1), 47–68.

Kennish, M.J., 2002. Environmental threats and environmental future of estuaries. Environ. Conserv. 29, 78–107.

Kinne, O., 1977. Environmental factors—salinity: animal—invertebrates. In: Kinne, O. (Ed.), Marine Ecology. John Wiley, New York, pp. 821–996.

Kotal, S.D., Roy, S.S., Bhowmik, S.K.R., 2014. Catastrophic heavy rainfall episode over Uttarakhand during 16–18 June 2013 – observational aspects. Curr. Sci. 107 (2), 237–245.

Kovach, W.L., 1998. MVSP–multi-variate statistical package for windows, Ver 3.0. Kovach computing services, Pentraeth.

Lambshead, P.J.D., 2004. Marine nematode biodiversity. In: Chen, Z.X., Chen, S.Y., Dickson, D.W. (Eds.), Nematology: Advances and Perspectives. CABI Publishing, Wallingford, United Kingdom, pp. 439–468.

Landers, S.C., Nichols, A.C., Barron, N.K., Schimmer, C.A., Tao, R., Yu, K., Stuart, P.M., Ólafsson, E., 2014. Nematode and copepod diversity (2012) from Louisiana near the Deep water Horizon oil spill. Proc. Biol. Soc. Wash. 127 (1), 47–57.

Madhu, N.V., Jyothibabu, R., Balachandran, K.K., Honey, U.K., Martin, G.D., Vijay, J.G., Shiyas, C.A., Gupta, G.V.M., Achuthankutty, C.T., 2007. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters—India). Estuar. Coast. Shelf Sci. 73, 54–64.

Manna, S., Chaudhuri, K., Bhattacharyya, S., Bhattacharyya, M., 2010. Dynamics of Sundarban estuarine ecosystem: Eutrophication induced threat to mangroves. Sal. Syst. 6 (8). http://dx.doi.org/10.1186/1746-1448-6-8.

McIntyre, A.D., 1977. Effect of pollution on inshore benthos. In: Coull, B.C. (Ed.), Ecology of Marine Benthos. University of South Carolina Press, pp. 301–312.

Michiels, I., Traunspurger, W., 2004. A three year study of seasonal dynamics of a zoobenthos community in a eutrophic lake. Nematology 6 (5), 655–669.

Moens, T., Vincx, M., 1997. Observations on the feeding ecology of estuarine nematodes. J. Mar. Biol. Assoc. UK 77, 211–227.
Neira, C., Sellanes, J., Soto, A., Gutiérrez, D., Gallardo, V.A., 2001. Meiofauna and sedimentary organic matter off Central Chile: response to changes caused by the 1997–1998 El Niño. Oceanol. Acta 24, 313–328.
Papa, F., Durand, F., Rossow, W.B., Rahman, A., Bala, S.K., 2010. Satellite altimeter-derived monthly discharge of the Ganga-Brahmaputra River and its seasonal to interannual variations from 1993 to 2008. J. Geophys. Res. 115, C12013. http://dx.doi.org/10.1029/2009JC006075.
Pearson, T.H., Black, K.D., 2001. The environmental impacts of marine fish cage culture. In: Black, K.D. (Ed.), Environmental Impacts of Aquaculture. Sheffield Academic Press, Sheffield, pp. 1–31.
Platt, H.M., Warwick, R.M., 1983. Free living marine nematodes, Part I, British Enoplids, Pictorial key to world genera and notes for the identification of British species. In: Kermack, D.M., Barnes, R.S.K. (Eds.), Synopses of the British Fauna. Cambridge University Press, Cambridge, pp. 1–307.
Platt, H.M., Warwick, R.M., 1988. Free living marine nematodes, Part II, British Chromodorids, Pictorial key to world genera and notes for the identification of British species. In: Kermack, D.M., Barnes, R.S.K. (Eds.), Synopses of the British Fauna (new series). Brill/Backhuys, Leiden, pp. 1–502.
Prandle, D., 2009. Estuaries: Dynamics, Mixing, Sedimentation and Morphology. Cambridge University Press, UK.
Przeslawski, R., Ahyong, S., Byrne, M., Wo¨rheide, G., Hutchings, P., 2008. Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. Global Change Biol. 14, 2773–2795.
Pusceddu, A., Bianchelli, S., Gambi, C., Danovaro, R., 2011. Assessment of benthic trophic status of marine coastal ecosystems: significance of meiofaunal rare taxa. Estuar. Coast. Shelf Sci. 93, 420–430.
Rao, G.C., Misra, A., 1983. Studies on the meiofauna of Sagar Island. Proc. Indian Acad. Sci. (Anim. Sci.) 92 (1), 73–85.
Sajan, S., Joydas, T.V., Damodaran, R., 2010. Meiofauna of the western continental shelf of India, Arabian Sea. Estuar. Coast Shelf Sci. 86, 665–674.
Sanduli, R., De Nicola, M., 1991. Responses of meiobenthic communities along a gradient of sewage pollution. Marine Pollut. Bull. 22, 463–467.
Sandulli, R., Semprucci, F., Balsamo, M., 2014. Taxonomic and functional biodiversity variations of meiobenthic and nematode assemblages across an extreme environment: a study case in a blue hole cave. Ital. J. Zool. 81, 508–516.
Santos, G.A.P., Derycke, S., Fonsêca-Genevois, V., Coelho, L., Correia, M., Moens, T., 2008. Differential effects of food availability on population growth and fitness of three species of estuarine, bacterial-feeding nematodes. J. Exp. Mar. Biol. Ecol. 355, 27–40.
Schratzberger, M., Gee, J.M., Rees, H.L., Boyd, S.E., Wall, C.M., 2000. The structure and taxonomic composition of sublittoral meiofauna assemblages as an indicator of the status of the marine environment. J. Mar. Biol. Assoc. U.K. 80 (06), 969–980.
Schratzberger, M., Dinmore, T.A., Jennings, S., 2002. Impact of trawling on the diversity, biomass and structure of meiofauna assemblages. Mar. Biol. 140, 83–93.
Semprucci, F., Colantoni, P., Baldelli, G., Rocchi, M., Balsamo, M., 2010. The distribution of meiofauna on back-reef sandy platformsin the Maldives (Indian Ocean). Mar. Ecol. Evol. Persp. 31, 592–607.
Semprucci, F., Colantoni, P., Sbrocca, C., Baldelli, G., Rocchi, M., Balsamo, M., 2011. Meiofauna in sandy back-reef platforms differently exposed to the monsoons in the Maldives (Indian Ocean). J. Mar. Syst. 87, 208–215.
Semprucci, F., Balsamo, M., Frontalini, F., 2014. The nematode assemblage of a coastal lagoon (Lake Varano, Southern Italy): ecology and biodiversity patterns. Sci. Mar. 78, 579–588.
Semprucci, F., Sbrocca, C., Rocchi, M., Balsamo, M., 2015a. Temporal changes of the meiofaunal assemblage as a tool for the assessment of the ecological quality status. J. Mar. Biol. Assoc. U.K. 95, 247–254.
Semprucci, F., Losi, V., Moreno, M., 2015b. A review of Italian researchon free-living marine nematodes and the future perspectives on theiruse as ecological indicators (EcoInds). Mediterr. Mar. Sci. 16, 352–365.
Semprucci, F., Balsamo, M., Sandulli, R., 2016. Assessment of the Ecological quality (EcoQ) of the Venice lagoon using the structure and biodiversity of the meiofaunal assemblages. Ecol. Indic. 67C, 451–457.
Sen, A., Ghosh, M., Khanderao, P., Das, S.K., Roy Chowdhury, D., Sarkar, P.K., Saha, R., Bhadury, P., 2016. Modern benthic foraminiferal assemblages from the world's largest deltaic mangrove ecosystem, the Sundarbans. Mar. Biodiv. 46, 421–431.
Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., 2007. The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Eds.), Cambridge: Cambridge University Press.
Somerfield, P.J., Rees, H.L., Warwick, R.M., 1995. Interrelationships in community structure between shallow-water marine meiofauna and macrofauna in relation to dredgings disposal. Mar. Ecol. Prog. Ser. 127, 103–112.
Steyaert, M., Garner, N., Van Gansbeke, D., Vincx, M., 1999. Nematode communities from the North Sea: environmental controls on species diversity and vertical distribution within the sediment. J. Mar. Biol. Ass. U.K. 79, 253–264.
Strickland, J.D.H., Parsons, T.R., 1972. A practical handbook of seawater analysis. B. Fish. Res. Board Can. 167, 1–310.
Sutherland, T.F., Levings, C.D., Petersen, S.A., Poon, P., Piercey, B., 2007. The use of meiofauna as an indicator of benthic organic enrichment associated with salmonid aquaculture. Marine Pollut. Bull. 54, 1249–1261.
ter Braak, C.J.F., 1986. Canonical correspondence analysis: a new eigen vector technique for multivariate direct gradient analysis. Ecology 67, 1167–1179.
Thilagavathi, B., Varadharajan, D., Manoharan, J., Vijayalakshmi, S., Balasubramanian, T., 2012. Taxonomy and Distribution of Benthic Foraminifera from the Sediment of Palk Strait, South East Coast of India. Int. J. Pharma. Biol. Arch. 3, 1129–1136.
Vanaverbeke, J., Merckx, B., Degraer, S., Vincx, M., 2011. Sediment-related distribution patterns of nematodes and macrofauna: two sides of the benthic coin? Mar. Environ. Res. 71, 31–40.
Vanreusel, A., 1990. Ecology of the free-living marine nematodes from the Voordelta (Southern Bight of the North Sea). I. Species composition and structure of nematode communities. Cah. Biol. Mar. 31, 439–462.
Venkataramana, V., Sarma, V.V.S.S., Reddy, A.M., 2017. Impact of river discharge on distribution of zooplankton biomass, community structure and food web dynamics in the Western coastal Bay of Bengal. Reg. Studies Mar. Sci. http://dx.doi.org/10.1016/j.rsma.2017.09.007.
Warwick, R.M., Platt, H.M., Somerfield, P.J.D., 1998. Free-living marine nematodes, Part III, Monhysterids, Pictorial key to world genera and notes for the identification of British species. In: Kermack, D.M., Barnes, R.S.K. (Eds.), Synopses of the British Fauna (New series). Field Studies Council, Shrewsbury, UK, pp. 1–296.
Wieser, W., 1953. Die Beziehung zwischen Mundhöhlengestalt, Ernährungswiese und 1000 Vorkommen bei freilebenden marinen Nematoden. Ark. Zool. 4, 439–484.
Zeppilli, D., Sarrazin, J., Leduc, D., Martinez Arbizu, P., Fontaneto, D., Fontanier, C., Gooday, A.J., Kristensen, R.M., Ivanenko, V.N., Sørensen, M.V., Vanreusel, A., Thébault, J., Mea, M., Allio, N., Andro, T., Arvigo, A., Castrec, J., Danielo, M., Foulon, V., Fumeron, R., Hermabessiere, L., Hulot, V., James, T., Langonne-Augen, R., Le Bot, T., Long, M., Mahabror, D., Morel, Q., Pantalos, M., Pouplard, E., Raimondeau, L., Rio-Cabello, A., Seite, S., Traisnel, G., Urvoy, K., Van Der Stegen, T., Weyand, M., Fernandes, D., 2015. Is the meiofaunaa good indicator for climate change and anthropogenic impacts? Mar. Biodiv. 45, 505–535.